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A monthly survey of programs and findings of the International Geophysical Year and the International Geophysical Cooperation–1959 as related primarily to United States programs. The Bulletin also reports on international programs in geophysics and space science that have grown out of the IGY, and on their results.

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Status of United States Scientific Programs in the Antarctic

The following material was prepared by Albert P. Crary, of the National Science Foundation. Dr. Crary is NSF's Chief Scientist for the US Antarctic Research Program. During the IGY, Dr. Crary was Deputy Chief Scientist of the US Antarctic Program, Scientific Station Leader at Little America IGY Station for two and a half years, and leader of the two major IGY oversnow traverses from Little America Station.

Since the close of the IGY, coordination and administration of the United States Antarctic Research Program has been the responsibility of the National Science Foundation. Prior to that time, development and supervision of US scientific programs in Antarctica were the responsibility of the National Academy of Sciences and its US National Committee for the IGY. Financial support was received by the Academy from the Congress through the National Science Foundation, and logistic support was afforded by the US Navy.

Even before the end of the observational phase of the IGY, in December 1958, it had become evident that world-wide, cooperative research in geophysics had proved more valuable than the most optimistic forecasts, and consequently would benefit from continued international study and cooperation. Accordingly, in 1957 and 1958, the IGY parent body, the International Council of Scientific Unions (ICSU), established several groups to coordinate the long-range post-IGY effort; among these was the Special Committee for Antarctic Research (SCAR), established in February 1958.

Following the pattern of the IGY, the National Academy of Sciences established in this country the Committee on Polar Research to cooperate with SCAR in coordinating international programs in Antarctica and to advise US agencies on the formulation of the post-IGY US Antarctic program. Laurence M. Gould, President of Carleton College, is the Chairman of CPR; Dr. Gould was also the Chairman of the USNC-IGY Antarctic Committee.

The US Antarctic Research Program now consists of research conducted at six Antarctic installations, augmented by oversnow traverses and field parties in selected areas, as well as in laboratories and research centers in the US. The Byrd, South Pole, and McMurdo Stations are wholly US stations. At Hallett Station the program is a cooperative New Zealand-US effort, as it was throughout the IGY. Since the end of the IGY, the Ellsworth and Wilkes Station programs have been conducted cooperatively with Argentina and Australia, respectively. (See Figure 1.)

Within NSF, Thomas O. Jones serves as Antarctic Program Director. Scientific projects of the US Antarctic Research Program are arranged by the National Science Foundation in consultation with the Committee on Polar Research. Government agencies with interests in the Antarctic are represented through the Interdepartmental Committee on Antarctic Research, a second advisory group assisting the Foundation. The US Naval Support Force, Antarctica, commanded by Admiral David Tyree, provides the operating personnel for the Byrd, Hallett, and South Pole Stations and for the Naval Air Facility at McMurdo Sound, and also furnishes logistic support generally.

The US scientific programs in Antarctica have been maintained at approximately the same man-power level as during the IGY. Although there has been a reduction in the number of stations wholly operated by this country, additional emphasis is being placed on biology and geology, which were not major fields of study during the IGY, and a scientific staff has been added at McMurdo. A major change in the mode of scientific operation has been the limiting of wintering-over personnel, for the most part, to scientists in upper-atmosphere disciplines and in meteorology. Summer personnel of the glaciological, biological, and geological programs can now fly to the continent in October or November and complete their work by January or February. The numerical breakdown of US scientific personnel for the post-IGY studies is shown in Table 1.

Table 1. Numerical Breakdown of US Antarctic Personnel for 1959 and 1960

	1959 Wintering-over Team	1959–60 Summer Team	1960 Wintering-over Team
Administration	0	7	0
Biology	3	11	2
Cartography	1	2	0
Geology	0	13	0
Glaciology	3	9	2
Meteorology	13	1	17
Oceanography	0	4	2
Psychology	0	1	0
Traverse Seismology & Gravity	2	2	1
Traverse Engineering	2	0	2
Upper-Atmospheric Physics	8	1	9
Total	32	51	35

Biological and Medical Sciences

The biological and medical sciences were not included in the official IGY Antarctic Programs; however, workers in these fields were encouraged to take advantage of the unique opportunities afforded by the remote and severe Antarctic environment, and some valuable work was done. Beginning with the 1958–59 austral summer, when six independent life-sciences programs were undertaken, the increase in work in these fields has been rapid; 13 life-sciences programs were conducted in the 1959–60 Antarctic summer. Three of these included wintering-over scientists.

At Wilkes Station, a University of Wisconsin investigator has conducted studies since early 1959 and will remain until early 1961. This program deals with the sexual and parental behavior and the orientation mechanisms of the Adélie penguin. Before migration of the penguins in February 1959, near the end of the 1958–59 summer season, 500 were banded, a census was taken, and observations were made of their weights, moulting habits, general behavior, and history. Studies were also made of the skua and other birds, and of seals.

During the 1959–60 summer, the complete Adélie reproduction cycle was studied: the penguins first arrived in mid-October, the first chicks were seen in mid-December, and the last Adélies were seen on February 3. Several thousand were banded and the program of behavior studies was successfully carried out. Other avian studies were made, when possible, on the skuas and petrels near the station and at other sites in the Windmill Island Group.

Fig. 1. *Approximate Thickness of the Antarctic Ice Cap. Thickness shown in 1000-meter intervals; heavy dashed lines are routes of US oversnow traverses thus far; light dashed lines indicate approximate borders of shelf ice. US and cooperative scientific stations are indicated as follows: SP—South Pole, LA—Little America, B—Byrd, M—McMurdo Sound, W—Wilkes, E—Ellsworth, and H—Hallett.*

At McMurdo Station, a complete biological and medical-science laboratory was established in the 1958–59 season by the Arctic Institute of North America (AINA). The laboratory is now being monitored, supplied, and operated by Stanford University. With this laboratory as a focal point, a great many diverse projects have been carried out in the McMurdo Sound area.

A University of Tennessee program to study land invertebrates began in October 1958 and continued until March 1960. Collections were made in a large area around McMurdo Sound and near Hallett Station. The study also included an attempt to determine how these invertebrates adapt themselves to climatic conditions, through a detailed microclimatic study near the surface.

A Stanford University biological program deals with size, age, growth, and metabolic rates of Antarctic fish. Particular reference

is made to adaptation of feeding habits to environment. Also under study are the identity, distribution, and abundance of inshore marine invertebrates. During the 1959–60 summer, this work on marine invertebrates was expanded to include studies of digestive and reproductive cycles. Considerable collections were made from bottom samples, and a quantative study was made of plant and animal plankton, particularly diatoms.

The Bernice Bishop Museum, of Honolulu, has carried out a thorough study of airborne organisms in the McMurdo Sound area, between New Zealand and Antarctica, and on an expedition into the Bellingshausen Sea, which included a voyage from the Palmer Peninsula to South America. Insect nets were hung on guy wires at the station, on special frames, and from ship riggings; patrols were also made in the McMurdo area for many hours at a time using light planes ("Otters") or helicopters of the US Navy. In Antarctica, results were generally negative, and between New Zealand and Australia the most southerly collections were made at about 55° S. More than 100 insects were collected between the Falkland Islands and Buenos Aires, but none were obtained south of the Falkland Islands.

Duke University made a study, at Hallett Station, of the water metabolism of the penguin, with emphasis on the role of sea water and salt in the food. It was found that newly hatched chicks have a well-developed salt gland, which can function immediately after hatching, and that the capacity for excretion of salt increases during development. In a series of tests, it was noted that birds subjected to water loads did not respond by heavy diuresis.

The Virginia Fisheries Laboratories is studying the parasites of Antarctic vertebrates and invertebrates. During the 1959–60 summer, the studies centered mainly on parasites from the fish Trematomus, and many types of parasites—flukes, roundworms, tapeworms, and leeches—were found in the digestive tracts of this fish. The work was also extended to other fish, and to seals and penguins. Roundworms and tapeworms were found in great abundance in the Weddell seals.

The University of Texas began the collection, isolation, and identification of airborne microbiological organisms early in the Antarctic summer of 1959. Collections of algae, lichens, and mosses were also made from many shore areas of McMurdo Sound, and monoxenic cultures of some algae were grown in the McMurdo laboratory. Collections were made of microbiological specimans in fresh water ponds and soils in the McMurdo Sound area, and in ice-pit and snow samples at Byrd Station, in the interior of Antarctica.

A biologist from the American Museum of Natural History was a member of the Bellingshausen Sea expedition, making observations of the habits and relative abundance of the Arctic tern, chinstrap penguin, Magellanic penguin, loggerhead, and other birds.

Antarctic bird-banding, initiated early in the IGY period, was continued under a program directed by Johns Hopkins University and including scientists from various US and foreign agencies cooperating at many sites in Antarctica. This program has already yielded much new information on the migratory patterns and life cycles of Antarctic birds.

Medical work continues on upper-respiratory-tract infections prevalent in Antarctic personnel following isolation; this work was begun in 1959. Through the cooperation of US Navy medical doctors, blood sera and swabs were collected from volunteers wintering over in Antarctica for study of viruses and bacteria. The epidemiological information obtained are of considerable interest with respect to furthering knowledge of viruses of the common cold.

Observations were carried out on the group behavior of an Antarctic oversnow traverse party by a psychologist from George Washington University. Considerable insight was obtained on the effects of stresses of

the traverse operation on authority, leadership, and work-production problems.

Cartography

During the Antarctic summer of 1959–60, extensive aerial photography for mapping purposes was accomplished by US Navy personnel. The P2V Neptune plane, instrumented for trimetrogon cameras, covered areas of the Sentinel, Horlick, Executive Committee, Victoria, and Commonwealth Ranges.

The establishment of ground control for the aerial mapping was continued on the oversnow traverses (Fig. 1) and by other ground parties when possible. Topographic engineers of the US Geological Survey accompanied the Byrd and Victoria Land traverses. A third engineer, on the Bellingshausen expedition, was able to locate accurately several exposed-rock areas on Thurston Island, which can be used as future ground-control points in this area.

The U.S.G.S. Cartographic Section continued with the preparation of Antarctic maps in the McMurdo Sound area and along the Budd and Sabina Coasts of Wilkes Land. Also, preliminary maps of the Horlick and Sentinel Mountains have been under preparation during 1960 for the use of geologists during the Antarctic 1960–61 summer. The Cartographic Section has also printed thousands of photographs of various Antarctic areas for the use of scientists in the preparation of their final reports.

The American Geographical Society has continued to maintain a current map of Antarctica on a 1:3,000,000 scale, using US and foreign geographic information as it is made available.

Geology

Though not an IGY discipline, much preliminary geological information was obtained by personnel from other disciplines, mainly on the oversnow traverses.

The bedrock geology of the Windmill Islands in Wilkes Land was examined by members of the Wilkes Station glaciological team. The bedrock consists of Precambrian metamorphic and igneous rocks. The metamorphics are very old rocks and appear to be remnants of a folded volcanic-sedimentary sequence, altered to biotite, hornblende, or magnetite-garnetiferous gneisses, containing intercalated bands of pegmatite.

The igneous rocks consist of coarse to porphyritic diorite, quartz diorite, syenite, and granite. They are generally featureless except for some basic dikes and faulting. The ages of two gneiss samples and a quartz diorite from this region are 950 and 1120 million years, as determined by the A^{40}/K^{40} method.

During the 1957–58 traverse from Ellsworth Station, the Dufek Massif, in the northern group of the Pensacola Range, was visited. The Pensacola Range lies between the Shackleton Range, in the Weddell Sea region, and the Horlick Mountains, at the southeast corner of the Ross Ice Shelf; its relationship to these ranges, however, is still indistinct.

The Dufek Massif was found to be a basic igneous complex with nearly horizontal layering and banding. On the basis of color, the rocks of the Massif were divided into two groups: (1) a medium-grained diorite, which grades locally into gabbro, anorthosite, or a gneissic-looking rock belonging to the gabbro-norite clan; and (2) a group of rocks resembling syenites or leucodiorites but petrographically also classified as gabbro-norite.

The Sentinel Mountains were very briefly visited by the Byrd traverse party of 1957–58 and by an airlifted party in 1959–60. Low-grade, folded metamorphic rocks were found in the western foothills of the range. The main range, as determined by field observations and study of aerial photographs, consists of strongly folded strata with an expected north to northwest trend and probably cut by intrusive rocks. The Sentinels are probably a typical linear

folded mountain system but their age and relation to the "Antarctic Andes" is unknown.

Rocks from the central range of the Horlick Mountains, visited by members of the Byrd traverse party of 1958–59, are relatively undisturbed and are elevated as block-type mountains. Lying unconformably on the exposed "basement" complex are fossiliferous Lower Devonian marine strata. The overlying succession of sedimentary rocks, assigned to the Beacon group, consists of graywackes, followed by sandstones, siltstones, shales, and coal seams. In the upper part, plant leaves (*Glossopteris*) and fossil wood are present. Major block-faulting and tilting, with vertical displacement of 2000 to 3000 meters, has created a steep northern escarpment which may be an extension or continuation of the escarpments of the Queen Maud and Royal Society Ranges.

During the traverse from Ellsworth to Byrd Station in 1958–59, specimens were collected from a nunatak at 81° 53′ S, 89° 20′ W. The specimens consist of two similar types of metamorphic rocks, one of which showed evidence of contact with an igneous rock; two samples of granitic rock; and a rock collected from talus. All of the specimens are unlike any rocks of the Beacon group. The metamorphic specimens may have been Precambrian or younger sedimentary rocks later intruded by granitics.

The Executive Committee Range, visited in early 1959 by a traverse from Byrd Station, consists of rocks of volcanic origin. The high peaks are almost exclusively made up of a variety of basalt, with olivine basalt predominant in the specimens collected.

During the 1959–60 Byrd traverse, investigations of the Toney Range showed it to be mostly volcanic, with basalt and basic agglomerates. Volcanic rocks lay unconformably over diorites on an uncharted nunatak at 76° S, 124° W. Nunataks at the south end of the Edsel Ford Range were also visited, and granite of probably batholithic proportions were noted intruding a metagraywacke sequence.

On the Bellingshausen Sea expedition, geologists from the University of Minnesota and the U.S.G.S. visited various sites on Thurston Island. The bedrock examined there is hornblende-bearing diorite gneiss cut by dikes. This series of rock has a northeast-southwest trend. No definite age determination has been made, but the rocks appear to be Andean or older. One small basaltic pebble gave evidence of volcanic origin.

The geologists also landed on different parts of Peter I Island, confirming that it is a basaltic volcanic island. Two wave-cut beaches were noted—one below sea level and the other at elevations of about 200 to 250 meters.

South Victoria Land was studied during the past two Antarctic summers by geologists from the U.S.G.S., Tufts College, and the University of Kansas. Programs of the U.S.G.S. included study of the pre-Beacon batholith and the stratigraphy of part of the Beacon sandstone. Results indicate that movement along the great Antarctic Horst may have begun in the early Precambrian.

Geologists from Tufts College studied Wright Dry Valley, elevated beaches in the vicinity, and the geomorphology of the Marble Point area of McMurdo Sound.

University of Kansas scientists studied the thermoluminescence of Antarctic limestones in an effort to determine their past thermal history. Preliminary results give an approximate minimum age for Antarctic glaciation of 170,000 years.

In the course of traverse operations in West Antarctica, a major sub-ice channel was located between the Ross and Bellingshausen Seas. A combination of magnetic, geologic, and seismic evidence indicated that this channel represents a fundamental division between geologic provinces. Gravity studies show West Antarctica to be in approximate isostatic equilibrium. They also show that the crust is continental in character, with the base of the crust at a

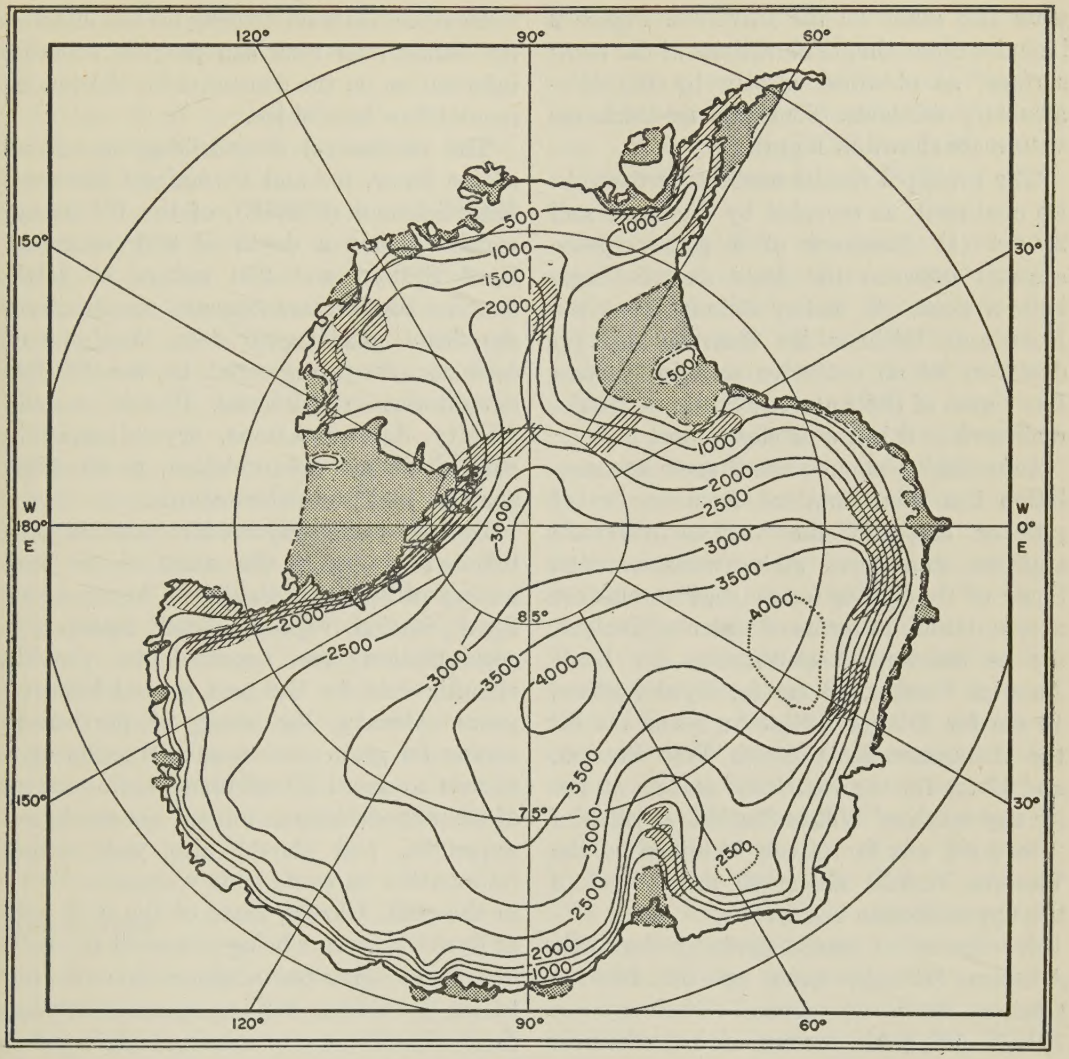

Fig. 2. *Approximate Elevations of the Antarctic Ice-Cap Surface. Elevations shown in 500-meter contour intervals; stipple pattern represents approximate known extent of ice shelves; line pattern represents regions in which there is much exposed land.*

relatively high average elevation. An extensive program of analysis of seismic, gravity, and magnetic traverse data is being conducted at the University of Wisconsin.

Glaciology

Glaciological studies in Antarctica since 1957 included the oversnow traverse work in inland regions, station glaciology, deep drilling, ice-deformation studies, and a general Ross Ice Shelf movement study.

Traverses since the beginning of IGY have covered more than 16,500 kilometers (10,250 miles). Figure 1 shows the various US traverse routes. The main glaciological information sought on the traverses was elevation of the ice surface; thickness of the ice, as determined by seismic, gravity, and magnetic observations; annual snow accumulation; and near-surface snow and firn properties. Studies in other disciplines

were also made on the traverses. Figure 2 includes approximate elevations of the snow surface, as obtained mostly by multiple-altimetry methods. Tentative ice-thickness values are shown in Figure 1.

The principal results concerning the sub-ice continent, as revealed by Figures 1 and 2, are (1) discovery of a great sub-ice channel between the Ross and Bellingshausen Seas, (2) better definition of the Ross and Filchner ice shelves, and (3) discovery of an extensive area in Victoria Land west of the Antarctic Horst where the rock surface is below or close to sea level.

Information about annual snow accumulation has been obtained from studies of pits or cores at the various Antarctic stations, and from stake measurements. Some of the figures for average annual net accumulation, in terms of water equivalent, are as follows: 24 centimeters for Little America Station, 16 cm for Byrd Station, 18 cm for Ellsworth Station, seven cm for the Amundsen-Scott South Pole Station, and 13 cm for the "satellite" station on the ice cap south of Wilkes Station. A value of 2 to 4 cm was tentatively obtained on the Victoria Plateau about 60 miles west of the upper Skelton Glacier.

Ice-movement studies made by the Little America traverse team on the Skelton Glacier show an annual discharge of 791×10^6 cubic meters of ice, which is sufficient to account only for the accumulation in the upper névé fields of the Skelton Glacier. It thus appears that the Victoria Land Plateau does not contribute ice to the western part of the Ross Ice Shelf through gaps in the mountains along the Antarctic Horst.

Strain rates obtained on the Ross and Filchner Ice Shelves show that the creep of the ice (slow, continuous horizontal strain) is about one meter per kilometer per year, and is at a maximum in the direction perpendicular to that of absolute ice flow. In general, the ice creep obeys theoretical patterns determined from thickness, density profile, and temperature profile. Such strain rates on floating ice not affected by sliding over rock can provide valuable information on the constants for the fundamental flow laws of ice.

The mechanical deep-drilling operations of the Snow, Ice and Permafrost Research Establishment (SIPRE), of the US Army, which reached a depth of 300 meters at Byrd Station and 250 meters at Little America Station, are expected to contribute significant glaciological data. Analyses of core samples transported to the SIPRE laboratories in Wilmette, Illinois, include density determinations, crystallographic studies, annual accumulation, geochemical analysis, and particulate counts.

Drill-hole temperatures have already contributed greatly to the study of the past history of the ice in the Little America and Byrd Station regions. Final figures for accumulation are expected to provide climatic data for the past several hundred years. Already, the study of particulate counts for grain sizes from a fraction of a micron to about 80 microns shows promise of helping determine annual accumulation sequences, and should also yield much information on world-wide volcanic activity in the past. Closing rates of the drill hole at Byrd Station are being measured annually and should give basic information relating to ice flow. Deep-drilling operations using thermal probes are now being tested, and it is hoped that this apparatus will be able to penetrate the entire thickness of the ice cap.

A program was begun in the summer of 1959–60 by the University of Michigan that may eventually provide information on absolute movement; differential movement, or creep; volume of ice discharge; and accumulation along the front of the Ross Ice Shelf from Little America to McMurdo Sound. Studies of ice deformation in the area north of Roosevelt Island, in the northeastern part of the Ross Ice Shelf, have yielded much information on the association of horizontal compressive stresses with firn folds and crevassing; these findings

should be of interest with respect to similar deformation problems in the rocks forming the earth's crust.

At the Byrd and South Pole Stations, in the Antarctic interior, absolute movement studies by means of accurate astronomical fixes have been initiated. These "star shots" will be repeated periodically, indicating motion of the ice cap beneath the stations. Annual gravity readings are also being made at the Pole Station to determine whether the ice cap has reached a steady state or is still either expanding or shrinking.

Glacial geology studies at McMurdo Sound early in the IGY outlined several Pleistocene glaciation periods in this area. Further studies in the lower part of the Taylor Dry Valley have led to identification of deposits laid down during four glacial advances as well as an inter-glacial deposit formed between the first and second advances. These glacial geology studies are continuing. Similar studies have also been carried out at the Wilkes Station and should contribute to the history of the ice sheet in that area.

Meteorology

The most extensive scientific efforts in the Antarctic have been made in meteorology. Data collections were the result of a joint effort by the US Weather Bureau and aerologists of the US Navy, and special observational programs as well as analysis of data have been accomplished by the Weather Bureau.

The main effort continues to be in the synoptic upper-air observations of temperature, pressure, humidity, and wind speed and direction, as observed twice daily with rawinsonde balloon flights. During 1959, 3812 rawinsonde balloon flights were made at all US and cooperative stations, totalling 87% of all scheduled flights. The average height of the balloon flights during 1959 was 21,500 meters, ranging from a winter average of about 18,000 meters to a summer average of about 24,500 meters. All data from US Antarctic stations are forwarded to the Weather Bureau's National Weather Records Center, at Asheville, North Carolina, for reduction, publication, and release to research units and to IGY World Data Centers.

Surface weather observations in Antarctica are maintained on a three-hourly basis. A "satellite" field station was also maintained near Wilkes Station during part of the year, and a second outlying station is planned for 1960 in order to increase the areal coverage of near-surface pressures, temperatures, and wind speeds and directions. During the flying season, the US Navy operated surface weather stations, making many rawinsonde releases, at Mile 160 on the Little America-Byrd trial and at the Beardmore Glacier camp. The Navy has also started an automatic-weather-station program in the vicinity of McMurdo Sound and in the Bellingshausen Sea area. The scope of these observations will be increased during the coming year.

Many additional meteorological programs are carried out at the Byrd, Ellsworth, Hallett, South Pole, and Wilkes Stations. The most extensive are the observations relating to energy-balance. Ground-based radiation studies are made with pyrheliometers, normal-incidence radiometers, and illuminometers. Beginning in April 1959 at Hallett Station, radio-metersonde equipment has been sent aloft several times a month to obtain vertical profiles of radiative heat transfer; this program has been extended to the South Pole and Byrd Stations.

Surface measurements of carbon dioxide were made in 1959 at the Ellsworth and South Pole Stations. Also at the Pole Station, US Weather Bureau Personnel operate Naval Research Laboratory equipment to measure radioactive fallout for the purpose of studying atmospheric motions.

In cooperation with the glaciological programs, meteorological observers at the South Pole, Byrd, and Wilkes Stations are measuring accumulation or ablation of snow,

or both, using a network of stakes. They are also measuring snow and ice temperatures with buried thermohms.

On the oversnow traverses, standard weather observations are made at regular intervals. Temperatures are also taken at a depth of 10 meters at all major stations on the traverses. It has already been demonstrated that 10-meter ice temperatures are very close to annual average near-surface air temperatures; hence, these measurements make it possible to obtain this important climatological data in remote areas without the need for permanent stations.

At the International Antarctic Analysis Center in Melbourne, Australia, a US Weather Bureau research meteorologist is assisting in the preparation of current weather charts at six constant-atmospheric-pressure levels from the surface to 300 millibars (about 26,000 feet), and of time cross-sections for selected stations south of 30° S. In addition to the analysis program, the staff at Melbourne also undertakes various research studies.

The US Weather Bureau has continued to maintain an Antarctic research group in Washington in accordance with its enormous data-collection program. The main research programs considered to date have concerned the horizontal transfer of energy, including net transfer of water vapor into the Antarctic continent; the distribution and variations of incoming and outgoing radiation; detailed studies of the sudden spring warming of the Antarctic stratosphere, and comparisons with Arctic conditions; studies of the ocean-atmosphere exchange of energy; and studies of atmosphere-icecap exchanges. A climatological study was also inaugurated in 1959 by the University of Wisconsin.

Oceanography

A very large amount of oceanographic data was collected during 1959 by personnel of the US Navy Hydrographic Office working on Task Force icebreakers. This data has included bathymetry, variation of water salinity and temperature with depth, shallow bottom samples, plankton hauls, etc. In 1959–60, oceanographic work included over 16,000 miles of sonic soundings, nearly 4000 miles of pack-ice reconnaissance, 7000 miles of continual surface temperatures, 1000 bathymetry lowerings, 43 ocean stations, three plankton hauls, and 15 bottom-core samples. Much of this work was done in the little-known Bellingshausen Sea area.

A limited amount of sub-Antarctic oceanographic work has been done by the research vessel *Vema*, of the Lamont Geological Observatory, Columbia University. These investigations concentrated on submarine geology, with the aid of numerous ocean-floor photographs, dredging, deep bottom cores (as much as 20 meters long), and seismic techniques. Past work of the *Vema* has been concentrated in the Scotia Sea area, but in early 1960 the ship cruised in the South Pacific between Australia and South America. The *Vema* is not able to cruise in ice-covered waters, however, and its activities are limited to Antarctic waters considerably north of the ice pack.

A shore-based oceanographic program was initiated in the summer of 1959–60 at McMurdo Station, thus continuing work done in 1959 by traverse-party members stationed at New Zealand's Scott Base. The main studies concern water temperatures, salinities, and currents, and details of ice conditions in McMurdo Sound. Tidal studies were made successfully during the IGY on both the Ross and Filchner Ice Shelves, over relatively deep water, by observation of gravity meter variations.

Seismology

At four US Antarctic stations, seismology equipment generally identical to that used during the IGY period is being employed. The equipment at the Byrd and South Pole Stations is operated under the direction of the US Coast and Geodetic Survey (USC&GS); at Hallett Station, the Lamont Geological Observatory directs the seismic

work; and at Wilkes Station it is directed by the California Institute of Technology. At Hallett and Wilkes Stations, the scientists operating the equipment are from New Zealand and Australia, respectively.

Information from these seismology stations is used in the world-wide earthquake epicenter program of the USC&GS; in the delineation of continental and oceanic crustal structure in the Antarctic; in the study of microseisms; and in the study of the propagation of "body" waves through the earth. It is expected that further studies of Antarctic crustal structure will soon be inaugurated at California Institute of Technology as a continuation of the earlier analysis of surface waves, which showed that continental structure in the south polar region may be limited to East Antarctica. Generally, it has been found that Antarctica is not a particularly active seismic region.

Upper-Atmospheric Physics

Collection of atmospheric-physics data in Antarctica continued during 1959 at approximately the same level as during the IGY. US scientists continued investigations at Byrd and South Pole Stations, while Argentine and Australian scientists conducted studies at Ellsworth and Wilkes Stations. At the joint NZ-US Hallett Station, New Zealand scientists continued their studies as during the IGY.

The aurora program consisted of three main parts: (1) visual observations directed by Cornell University, and (2) all-sky camera and (3) patrol spectrograph observations by the Geophysics Research Directorate of the Air Force Cambridge Research Center. The aurora studies generally cover the portion of the year from April to September, though at Wilkes, the northernmost station, observations were possible for some nights in early March and October.

Cloudy weather limited auroral observations by varying amounts. Thus, on the average, it was possible to conduct observations at all stations for about 60% of the total possible observing time. Wilkes Station had the highest number of cloudy days, limiting observations to about 38% of the total possible observing time, while at the South Pole Station it was possible to conduct observations 85% of the time.

Additional equipment for 1960 includes an airglow photometer and a riometer at Hallett Station, where a US aurora scientist is now working. Reduction of auroral data has been conducted according to international agreements.

Geomagnetic recordings in Antarctica are obtained by the USC&GS at the Byrd and South Pole Stations, while cooperative programs, using US equipment and scientists of other countries, are being carried out at Hallett, Ellsworth, and Wilkes Stations. Temporal variations of the magnetic-field vector are obtained with standard magnetographs at all stations, and rapid-run magnetographs are also in use at Byrd and Wilkes Stations.

The building originally constructed at Little America Station to make absolute magnetic-field measurements has been moved to the South Pole Station, where absolute values were obtained for the first time in 1959. At all of the Antarctic stations, absolute measurements are made periodically, usually once a week if conditions are quiet but only once a year at Hallett Station. At the Byrd Station, a proton-precession magnetometer will soon be in use to provide an absolute standard.

Vertical-incidence sweep-frequency ionosphere sounders furnished by the National Bureau of Standards are operated at the Byrd, South Pole, Ellsworth, Hallett, and Wilkes Stations. These sounders make 15 second sweeps through a frequency range of 1-15 mc/sec every 15 minutes, or on a more accelerated time schedule during special periods.

Radio-noise equipment has also been in operation at Byrd Station to obtain the average power level of radio noise at eight frequencies between 51 kc/sec and 20

mc/sec. This program has been only partially successful because of the high level of radio noise associated with station activities. It is planned to relocate this part of the scientific program at a greater distance from the station in the near future.

At Byrd and Ellsworth Stations, a program of whistler monitoring was conducted during 1959 using a loop antenna. The 15.5-kc pulse broadcast over station NSS, Washington, D. C., was also monitored at regular intervals. Whistlers have generally been at a maximum during the April-to-September period, and at peak periods of activity as many as 100 whistlers per minute have often been recorded. The NSS whistler-mode echoes are observed only during Antarctic winter months. Additional whistler-monitoring equipment is now in use at the South Pole Station.

Cosmic-ray studies were made only at Ellsworth Station during 1959. Both the neutron monitor for low-energy cosmic rays and the meson telescope for high-energy particles were used. Near the end of 1959, however, the meson-telescope observations were discontinued. During the 1959–60 summer, cosmic-ray neutron-monitor equipment was installed at McMurdo Station.

Analysis of upper-atmospheric-physics data progressed well, with the main concentration thus far mostly on descriptive aspects. The location of the southern auroral zone has now been fairly well defined, and "magnetic bays" and ionosphere variations shown in the records of various stations has been documented. In general, a surprising degree of agreement between auroral, magnetic, ionospheric, and other upper-atmosphere phenomena has been found, but only a few of the features have as yet been studied in detail.

From the cosmic-ray data obtained at Wilkes Station during the IGY, it appears that seasonal variations of primary cosmic-ray activity may be related to atmospheric conditions. Also the data indicates that all solar flares may result in cosmic-ray-intensity increases, although these would be subject to variations related to geographic distribution.

Scientist Exchange Program

During the IGY, exchange of scientists in Antarctica between the US and other nations associated with SCAR added considerably to coordination and cooperation between nations and increased mutual knowledge of the variety of scientific methods and equipments used by them.

Beginning late in 1959, a further exchange of scientists between the US and USSR was made and will continue until early 1961. At the USSR Mirny Station, a US seismologist from the California Institute of Technology is at persent carrying out gravity, magnetic, and seismic researches in the vicinity of the station; he will also participate in one of the USSR oversnow traverses during the Antarctic summer of 1960–61. A USSR glaciologist is conducting special studies at the US McMurdo Station and will participate in a US traverse to the South Pole in 1960–61.

A French glaciologist participated in the US Victoria Land traverse during the Antarctic summer of 1959–60. Since he had previously worked with the French traverse party south of Durville and Charcot Stations, he was thus enabled to extend his snow-accumulation and geochemical studies in the same general area.

The Echo Communications Satellite

The Echo I satellite, a large inflatable sphere designed to serve as a passive, high-altitude reflector for long-range communications signals, was launched by the United States at approximately 5:40 am EDT, Friday, August 12, 1960, from Cape Canaveral, Florida. About 20 minutes later, the satellite, designated 1960 Iota 1, was injected into a high, nearly circular orbit by the third-stage rocket of the new Delta vehicle used for the launch. The third-stage rocket casing, which is also in orbit, has been designated 1960 Iota 2.

Well in advance of the launching, the National Aeronautics and Space Administration (NASA), which directs Project Echo, requested the National Academy of Sciences to invite researchers in other countries to use the satellite for experiments of their own. Accordingly, the Academy's Space Science Board (SSB) relayed this invitation and detailed information on Project Echo to its international counterpart, the Committee on Space Research (COSPAR), for transmission to all COSPAR participants.

As soon as it had been ascertained that 1960 Iota 1 was in orbit, a message giving orbital information and other details was sent by SSB to COSPAR for distribution, and to SPACEWARN (which also functions as the World Warning Agency—AGIWARN—established during the IGY) for dissemination to the world scientific community generally. To assist experimenters in other countries, NASA is providing tracking data for distribution via SPACEWARN. Data obtained in the course of the Echo experiment will be forwarded to COSPAR and will also be deposited in the IGY World Data Centers.

Cooperating closely with NASA in the Echo experiment are the Bell Telephone Laboratories (BTL), the NASA Jet Propulsion Laboratory (JPL), and the Douglas Aircraft Company. BTL, under contract to NASA, is working together with JPL in a major phase of the experiment—transmitting communications signals from coast to coast by reflection from the satellite's surface. The Douglas Aircraft Company, under contract to NASA, designed and constructed the Delta launch vehicle and conducted the countdown. A large number of other private and public agencies also participated in the design and construction of the numerous rocket and satellite components and are taking part in the experiment and in tracking operations.

Orbital Data

Program plans for 1960 Iota 1 called for a circular orbit at a nominal altitude of 1000 statute miles. The orbit achieved has a perigee of about 945 miles and an apogee of about 1049 miles, nearly as intended. The satellite's velocity is approximately 15,973 mph at perigee and 15,643 at apogee. The orbit is inclined to the equator at an angle of 47.24° (an orbital inclination of 47° was intended) and the satellite's period of revolution is 118.3 minutes. The satellite is expected to remain in orbit for about one year.

Satellite Characteristics

The satellite, developed at NASA's Langley Research Center, has a diameter of 100 feet when inflated and a surface area of about 31,400 square feet. It is made of 82 tapered segments of Mylar polyester film 1/2-mil (1/2000-inch) thick, or about half the thickness of the cellophane on a cigarette package. The outside of the shell is covered with vapor-deposited aluminum less than 1/25,000-inch thick. The aluminum film can reflect over 98% of all radio waves

of frequencies up to 20,000 megacycles per second. In addition, this surface is highly reflective to light, facilitating optical tracking; it also exerts some control over the satellite's temperature.

The sphere was carried into orbit folded accordion-fashion inside a magnesium container 26.5 inches in diameter (Fig. 3). Before launch, both sphere and container were pumped almost entirely free of air in order to slow the sphere's inflation rate when orbit was achieved. After release from its container, the sphere first began to inflate gradually as the small amount of residual air left inside expanded. Further inflation was accomplished by the 30 pounds of sublimating powders inserted in the sphere before it was folded and placed in its container—ten pounds of benzoic acid continuing the expansion begun by the residual air, and the remaining 20 pounds of anthraquinone sustaining inflation until the sphere reached its full dimensions.

Anthraquinone was used because it has a very low vapor pressure, thus maintaining low internal pressure inside the sphere—about .00004 pounds per square inch. It was expected that the sphere would sustain many small punctures from cosmic dust and micrometeorites, permitting the gases to escape. However, the low internal pressure slows the leakage of gases from the satellite, thus maintaining its shape and increasing its life to the maximum possible length of time. Early in August, the satellite survived the Perseid meteor shower with no apparent serious damage.

Sunlight plays an important role in maintaining the sphere's shape, since the sublimating powders turn into gas at temperatures just above freezing, while the satellite temperature is well below freezing once out of the sunlight. In continuous sunlight, the temperature was expected to average about 240° F. Owing to the height of 1960 Iota 1's orbit and to its position relative to the Earth and sun, the satellite was in continuous sunlight for its first two weeks in orbit. After this, the relative positions changed and the sphere was at times in the Earth's shadow, causing its temperature to fall below freezing and any remaining gases to solidify. The experimenters were interested to learn if the satellite would re-inflate when once again in sunlight, and in what form. At the end of August, after increasing periods in the Earth's shadow, no change could be discovered in the sphere's size, shape, or ability to reflect radio signals. If it had not returned to its spherical shape, it would no longer have been useful for communications since signals would be reflected non-uniformly from a misshapen surface.

Two wafer-like transmitters for use as tracking beacons are attached to opposite sides of the sphere's equator. Each beacon is about 10 inches in diameter, 3/8-inch thick, and weights about 11 ounces. Each is equipped with 70 solar cells, five nickel-cadmium storage batteries, and a small whip antenna. Originally coiled into spiral grooves in each beacon, the antennas sprang perpendicularly outward from the sides of the sphere when it inflated.

The total weight of the satellite at launch was 167.4 pounds, broken down as follows: plastic sphere, 132 lbs; aluminum covering, 4 lbs; sublimating powder, 30 lbs; two tracking beacons, 1.4 lbs. The container that carried the folded sphere into orbit weighed 24 lbs, and the third-stage casing, in orbit with the sphere, weighs about 50 lbs minus propellant.

The Experiment and First Results

The primary purpose of the Echo experiment was to test the feasibility of using satellites as passive reflectors of radio and television signals for long-range transmissions. It has become increasingly apparent during the past few years that present communications lines are greatly overcrowded and barely able to keep up with demand, which, moreover, continues to grow. Among the efforts to meet this problem is experimentation with both "passive"

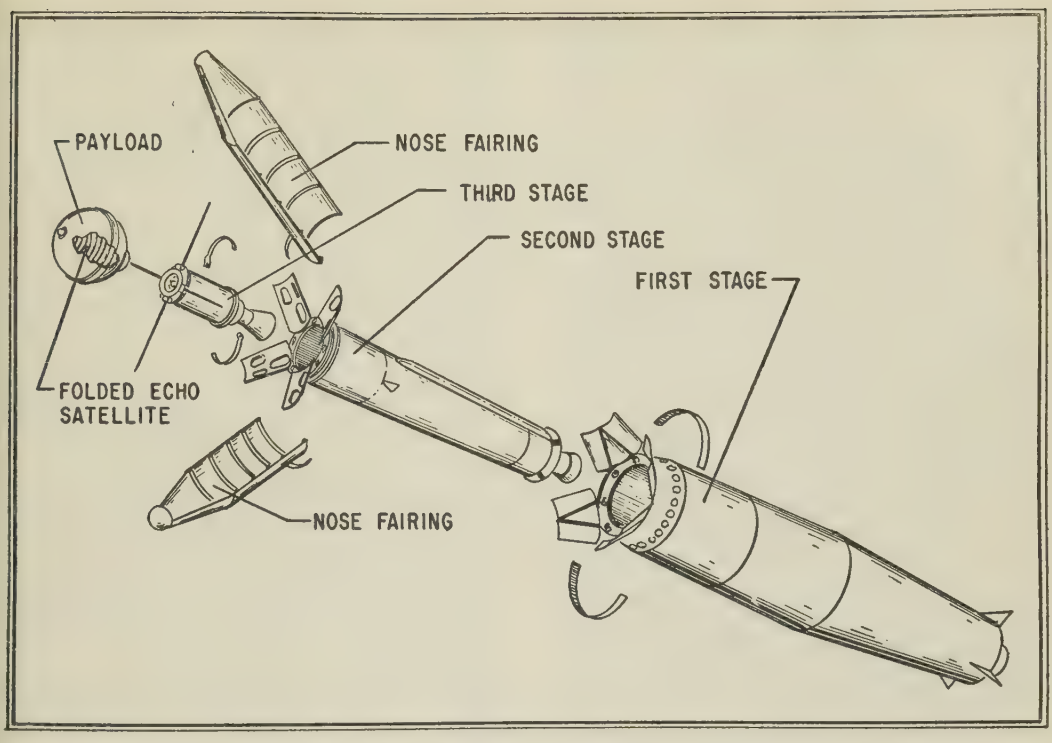

Fig. 3. *Delta Launch Vehicle and Payload Container With Folded Echo Satellite.*

and "active" satellite techniques. In the former, powerful signals are bounced off the reflective surface of a satellite; in the latter, weaker signals are received, amplified, and re-transmitted by radio equipment carried by the satellite.

The two primary stations taking part in the Echo experiment are the Bell Telephone Laboratories facility at Holmdel, New Jersey, and NASA Jet Propulsion Laboratory station at Goldstone, California. The aim was to bounce frequency-modulation voice transmission between the East and West Coasts of the United States off the highly reflective surface of the orbiting satellite.

BTL transmits on a frequency of 960 mc/sec for reception at Goldstone, and JPL is using a frequency of 2390 mc/sec for transmission to the Holmdel station. The Goldstone station uses two 85-foot-diameter paraboloid antennas, one a receiver and the other a transmitter. BTL is transmitting with a 60-foot dish and receiving with a specially constructed horn-reflector antenna. This 20 × 20 foot antenna, which is shaped like a steam-shovel scoop, is a recent development designed to reduce radio-noise interference.

The experiment proceeds as follows: First, orbital data is sent by Goddard Space Flight's Computing Center to both JPL and BTL for use in positioning the receiving and transmitting antennas. To set up the communications link, BTL then "illuminates" the sphere with a 960-mc/sec signal, which bounces off the satellite in all directions. A portion of this scattered energy is picked up by the Goldstone station, where the receiver is pointed toward the satellite. Goldstone then transmits a 2390-mc/sec signal to BTL, completing the communications link. Transmitting power at both stations averages about 10 kilowatts.

On any one pass, the satellite is mutually "visible" between the East and West Coasts for as much as about 16 minutes.

At 7:39 am EDT, August 12, two hours after launch and on the satellite's first pass over the United States, JPL began transmitting the following message by the President of the United States:

> "This is President Eisenhower speaking. It is a great personal satisfaction to participate in this first experiment in communications involving the use of a satellite balloon known as Echo. This is one more significant step in the United States program of space research and exploration. The program is being carried forward vigorously by the United States for peaceful purposes for the benefit of all mankind. The satellite balloon which has reflected these words may be used freely by any nation for similar experiments in its own interest. Information necessary to prepare for such participation was widely distributed some weeks ago. The United States will continue to make freely available to the world the scientific information acquired from this and other experiments in its program of space exploration."

The message was received clearly at the BTL Holmdel station beginning at 7:41, and continuous transmission over a period of about 14 minutes was also successfully received, with only a few interruptions when either the transmitter or receiver momentarily lost contact with the balloon.

A large number of other successful transmissions, from other stations and by other cooperating agencies, have since been made. These include two-way telephone conversations, "double hops" using an intermediate station to receive and re-transmit messages via the satellite, and transmission of a wirephoto image of the President.

Launch Vehicle

The new Delta vehicle used to put Echo 1 into orbit is an improved version of the three-stage Thor-Able satellite and space-probe booster. The Delta has a total height of 92 feet, a maximum diameter of eight feet, and a fueled weight of nearly 112,000 pounds. It is similar in configuration to the Thor-Able, but contains an improved auto-pilot and radio-guidance system for first- and second-stage powered flight and precise altitude control for the longer coasting period between second-stage burnout and third-stage ignition. (See Figure 3.)

The first stage of the Delta vehicle used in the launch was a Douglas Thor weighing about 100,000 pounds fueled and having a thrust of approximately 150,000 pounds. It was propelled by liquid oxygen and kerosene for about 160 seconds of powered flight before burnout. The second stage, an Aerojet-General rocket, was modified from the second stage of the Vanguard and Thor-Able vehicles. It weighed more than 4000 pounds fueled and developed a thrust of about 7500 pounds. After ignition, following first-stage burnout, the second stage was under powered flight for about 115 seconds and then coasted for about 15 minutes, to a position approximately 800 miles above the Earth's surface and 2300 miles down range from the launch site.

The third stage is an Allegany Ballistics Laboratory solid-propellent rocket weighing over 500 pounds fueled and developing about 3000 pounds of thrust. It was also used originally in the Vanguard and Thor-Able vehicles. In rapid sequence at the end of the second-stage coasting period, the third stage was "spun up" for stability to 120 revolutions per minute by small spin rockets, ignited, and separated from the second stage by explosive bolts. The third stage then provided power for about 40 seconds in order to achieve orbital velocity of about 16,000 miles per hour.

After third-stage burnout, de-spin rockets slowed the rotation and the empty casing was separated from the payload by a spring. In addition to being slowed slightly by the spring, the separated third-stage casing was tumbled by a small lateral rocket so that it would not interfere with the satellite. About two minutes after injection into orbit, an explosive in the form of a linear charge around the equator of the spherical payload container separated the two halves of the container and released the satellite, allowing it to expand to its full size.

Radio Equipment and Tracking

The two tracking beacons attached to the sphere transmit continuously at a frequency of 107.94 mc/sec and at a power level of 10 milliwatts. The solar cells are employed to recharge the beacons' batteries, and the transmitters are inter-connected so that if one is facing away from the sun it will nevertheless receive power from the solar cells of the other beacon as well as from its own.

The third stage of the launch vehicle (1960 Iota 2) is also equipped with a telemetry package to assist in determining the satellite's initial orbit and to signal payload separation from the third stage. This radio transmitted continuously on a frequency of 108.06 mc/sec at a power level of 300 milliwatts. It was battery powered and was expected to last two or three days.

Tracking for the Echo project is under the over-all direction of NASA's Goddard Space Flight Center. Tracking services are provided by BTL's station at Cape Canaveral; the Air Force radar test site at Trinidad, B. W. I.; JPL's Goldstone station in California; the Lincoln Laboratory Millstone Hill radar station, Massachusetts; NASA'S Minitrack network; and optical tracking stations of the Smithsonian Astrophysical Observatory.

Initial trajectory data were provided by BTL's guidance radar at Cape Canaveral and, during the launch, Minitrack stations at Fort Myers, Florida, Antigua, B. W. I., and Ascension Island (UK), tracked the third-stage beacon. After payload separation, Trinidad, which also tracked the third stage, "skin tracked" the payload by radar to observe inflation of the sphere.

Optical tracking, which also plays an important role in the experiment, is performed primarily by the 12 Baker-Nunn camera stations set up during the IGY and operated by the Smithsonian Astrophysical Laboratory, and by Moonwatch teams throughout the world. To the naked eye, 1960 Iota 1 has the brightness of a bright star.

The first positive confirmation that the sphere was in orbit came from Woomera, Australia, where the beacon signal was received and the satellite was observed visually on the first pass. The next was from Goldstone, which also both heard and saw the satellite.

World Days Report for IGC-1959

This report is one of a series issued periodically during and following the IGY. Earlier reports in the series appeared in *Bulletin Nos. 5, 10, 19, 23, 28,* and *31. Bulletin No. 23* contains a brief summary of solar flares, related geomagnetic activity, and World Warning Agency (AGIWARN) decisions during the IGY, and *Bulletin Nos. 28* and *31* review the first three-quarters of IGC-1959. The present report covers the fourth quarter of 1959 and summarizes the IGC-1959 period as a whole, comparing it with the IGY period and relating it to the current solar cycle.

Solar Flares, Geomagnetic Disturbances, and AGIWARN Decisions, Fourth Quarter, 1959

During the last quarter of 1959, the IGC World Warning Agency, operated by the National Bureau of Standards at Fort

Belvoir, Virginia, recorded 11 geomagnetic disturbances. Although this total was the same as that for the preceding quarter, the number of storms classified as severe declined from five to two.

Eight of the 11 disturbances were of the type common to the declining phase of the sunspot cycle, having longer duration than the typical solar-maximum storm but only minor-to-moderate severity. (Sunspot cycles average about 11 years from minimum to minimum, varying in length from 9 to 13 years; the present cycle began in 1954 and reached a maximum in 1957–58, during the IGY period.)

Most of the storms during the last quarter of 1959 tended to fit the weak 27-day recurring patterns of geomagnetic activity associated with the sun's 27-day rotation period. Others, which did not fit existing 27-day recurrence patterns, were thought to be the first disturbances of newly developing patterns. For about two years immediately following sunspot maxima, recurrent patterns are weak and difficult to discern; the tendency toward 27-day recurrence of geomagnetic storminess is expected to become stronger, however, as the next sunspot minimum is approached.

Only three of the magnetic storms recorded during the quarter could be associated with specific observable solar activity. Although not particularly severe, they generally exhibited the other characteristics of the typical solar-maximum storm—sudden beginning, short duration, and nearly simultaneous radio-propagation effects. Three of the five whole-day radio disturbances and 11 of the 34 six-hour disturbed-radio-quality figures observed during the quarter were associated with the sudden-commencement storms.

Solar activity was less evident than during the preceding quarter, with only two flares evaluated as Class 3 or greater in importance, compared with 14 in the third quarter. The two major flares occurred during the November 25-December 8 passage across the sun's disk of an outstandingly active center, which contained a giant sunspot group and was the source of at least 15 flares evaluated as Class 2 or greater. Though the region displayed activity of the type normally associated with severe radio and magnetic disturbance throughout its transit, such effects did not materialize.

The following is a list of major solar flares, geomagnetic disturbances, world-wide geophysical Alerts, and Special World Intervals (SWI) for the fourth quarter of 1959.

Oct	1	04xx	Magnetic storm begins
		1600	Alert issued*
	2	11xx**	Magnetic storm ends
	3	17xx	Severe magnetic storm begins
	4	1600	Alert issued; auroras expected
	7	13xx	Severe magnetic storm ends
	18	01xx	Magnetic storm begins
		1600	Alert issued
	19	14xx	Magnetic storm ends
	29	2347	Magnetic storm begins
	30	1600	Alert issued
Nov	5	16xx	Magnetic storm ends
	23	00xx	Magnetic storm begins
		1600	Alert issued
			SWI starts†
		21xx	Magnetic storm ends
	24		SWI finishes
	27	2350	Severe magnetic storm begins
	28	1600	Alert issued; auroras expected
			SWI starts
		2010	Class 3 flare; slow S-SWF††
		23xx	Severe magnetic storm ends
	29		SWI finishes
	30	07xx	Magnetic storm begins
		1600	Alert issued
			SWI starts
		1720	Class 3 flare; S-SWF††
Dec	2		SWI finishes
	4	06xx	Magnetic storm ends
	5	0659	Magnetic storm begins
			1600 Alert issued
	6	11xx	Magnetic storm ends
	13	17xx	Magnetic storm begins
	16	18xx	Magnetic storm ends
	23	1527	Magnetic storm begins
	24	14xx	Magnetic storm ends
	26	11xx	Magnetic storm begins
	27	1600	Alert issued
	30	21xx	Magnetic storm ends

Notes:

* No ending times for Alerts are issued, as was done during the IGY; this is now left to the discretion of individual observatories.

** "xx" indicates gradual beginning or ending of a disturbance, following the hour indicated, such that the precise moment could not be determined.

† SWI's, when warranted, start at the time the

associated Alert is issued; they finish at the end of the day indicated.

†† Slow S-SWF—slow short-wave fadeout (taking 5–15 minutes) and gradual recovery; S-SWF—sudden-wave fadeout and gradual recovery.

Summary for IGC-1959

During IGC-1959, AGIWARN recorded 39 geomagnetic disturbances. Regional Advance Geophysical Alerts were issued announcing 26 of these storms, and 31 were of sufficient severity to warrant the issuance of world-wide Geophysical Alerts. Only nine of the storms during IGC-59 can be classified as major disturbances, using a daily storm index of $A \geq 50$ as the criterion. SWI were declared in association with six of these. (The A-index measures geomagnetic activity on a linear scale ranging from 0 to 400; see *Bulletin No. 31* for a more detailed discussion.)

SWI's were in effect 14 days during IGC-59. Seven of these days were associated with the six major storms mentioned above; the other seven were distributed among the remaining 30 less-severe disturbances. Three of the nine major disturbances began gradually. The other six were of the sudden-commencement type associated with observable solar phenomena. Two of the three major disturbances for which no SWI were declared were of the gradual-beginning type.

IGC-1959 began less than a year after sunspot maximum and the smooth monthly sunspot number had dropped only about 12%. Thus, geomagnetic activity at the beginning of IGC-1959 was still comparable to that during the IGY. By the end of IGC-59, however, the smoothed monthly sunspot number showed a 36% decrease from the maximum and geomagnetic activity more typical of sunspot minimum had begun to occur.

The frequency of geomagnetic disturbances during IGC-1959 was essentially the same as during the IGY, but the storm characteristics exhibited marked change as the sunspot number dropped. Of the first 21 IGC-1959 disturbances, 17 began suddenly and, in most cases, were associated with important solar flares or other violent visible solar activity. Of the last 18 storms, only seven began suddenly. The remaining 11 storms began gradually and were generally longer but not as severe as the sudden-commencement disturbances. Many exhibited a cyclic pattern, tending to recur every 27 days.

The diminishing activity of the sunspot cycle as IGC-1959 progressed was not reflected by a corresponding decrease in the number of Advance Geophysical Alerts for solar flares from the beginning to the end. Of the 19 flare alerts issued in 1959, eight were in the first half of the year and 11 in the second half.

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